Delamination onset in composite materials due to fatigue loading

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The study of delamination onset due to fatigue loading and evaluation of the critical value for fracture has relevant interest for helicopter applications. At present, Leonardo Helicopter Division has a number of test programs in progress, with the objective of supporting validation of manufacturing transfer and change of material for alternative supplier. In the near future, fracture mechanics tests will support the design of composite components having improved tolerance to accidental damage and higher durability.
It is expected that scatter in values of fatigue threshold and of residual static strength will be properly addressed in dry and hot-wet aging conditions at efficient costs and schedule by adequate number of replicas.
Within such a framework and with such objectives, an experimental program has been carried out in a cooperation between Leonardo Helicopter Division and the University of Pisa, Dept. of Civil and Industrial Engineering, for the evaluation of the delamination resistance of various composite materials systems. Typically, static fracture toughness tests were performed in Cascina Costa premises of Leonardo, while fatigue tests were performed in Pisa.
Standard DCB, ENF and MMB specimens were used. Even if the fatigue testing standard procedure for the assessment of resistance to delamination onset has been issued by ASTM only for mode I, a procedure analogous for the mode II and mixed mode conditions (I + II) has been defined, on the basis of appropriate variants of the static test procedures. In all the fatigue tests a conventional condition of 5% stiffness reduction has been considered as the end of the test.
The evaluation campaign has been complemented with the assessment of environmental conditioning effects, by means of additional tests carried out in mode I and II only: saturated specimens have been subjected to static tests in HT conditions and to fatigue tests in RT conditions.
The paper presents the results of the fatigue delamination onset, in terms of initial Gmax value vs. number of cycles, the SERR being normalised with the critical static value. Three materials systems have been selected: a carbon epoxy unidirectional material, a carbon epoxy 5-harness satin fabric and a glass fibre epoxy system. Normalised curves show a common trend and allow the identification of threshold values for the evaluation of defects tolerance in service and in manufacturing.
The effect of environmental conditioning is different for the fracture toughness, according to the loading mode: in mode I situations, moisture absorption and high temperatures induce a more plastic behaviour which is reflected in higher toughness values, while for the mode II situations a substantial reduction in toughness is observed.

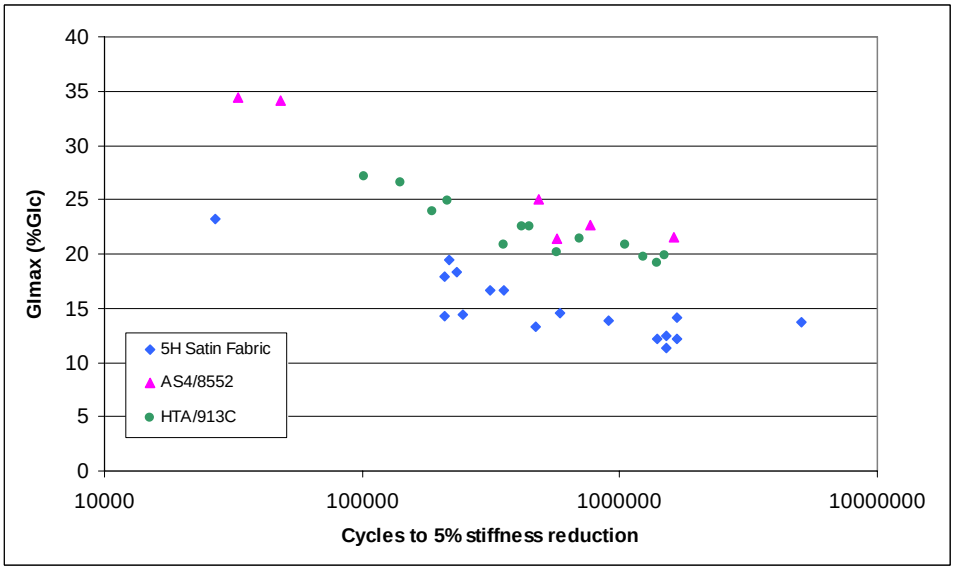

Fig. 1 – Normalized G1max – Number of cycles to 5% stiffness reduction for various materials systems.

As an example, Fig. 1 shows a plot of the G1max at the beginning of the constant amplitude displacement test, normalized with the critical value, as a function of the number of cycles to observe a 5% stiffness reduction. A rather common trend can be observed, with the test data from a fabric material that require some special comment.
A numerical effort is in progress to develop a fatigue degradation law for cohesive elements to be used in FE analyses. Numerical simulations of DCB and ENF tests have been conducted to study the sensitivity of the developed damage law to tuning parameters, that can be effectively calibrated using the experimental data base.

Keywords: Delamination onset, environmental effects, fatigue, threshold